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Investigation of surface roughness in machining of aluminum alloy with EDM

Sefika KASMAN[1], Nihat TOSUN[2]

[1]Dokuz Eylul University, Izmir Vocational School, 35160 Izmir, Turkey

[2]Firat University, Engineering Faculty, Mechanical Engineering Department, 23119 Elazig, Turkey

ABSTRACT: In this study, the relationship between surface roughness of workpiece and process parameters and was investigated for AA7075 aluminum alloy with electrical discharge machining (EDM). Experiments were conducted under different process parameters, namely, current, pulse on-time, pulse off-time, gap voltage and electrode material. The settings of machining parameters were determined by using Taguchi experimental design method. The level of importance of the machining parameters on the performances characteristics is determined by using analysis of variance (ANOVA). The optimum machining parameters combination was obtained by using the analysis of S/N ratio

Keywords—EDM, surface roughness, ANOVA, aluminum.

I. INTRODUCTION

The surface quality is one of major critical issues in precision machining operations. The non-conventional processes like laser assisted machining, electro discharge machining and water jet have been helped to improve precision machining for 20 years. Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes and proves to be an effective alternative comparing to traditional manufacturing processes [1]. Material removal in EDM is based on the electrical discharge erosion effect of electric sparks occurring between tool and work piece submerged a dielectric liquid. Material removal takes place as a result of the generation of extremely high temperatures generated by the high-intensity discharges that melt and evaporate the two electrodes. In addition, there is no mechanical contact of the tool with the workpiece during the machining process. Therefore, it is very effective in machining very hard and high-strength materials [1-6]. EDM is especially effective in machining hard die steels, complex cavities and small workpieces. Die casting, injection moulding, forging, extrusion, upset forging and powder compaction dies are manufactured using EDM technology [6]

The most of the published studies are focused on effects of process parameters in EDM on the surface quality, material removal rate, electrode wear rate, dimensional and geometrical accuracy of the workpieces. The literature review showed that the selected materials in the studies are commonly tool steels, tungsten carbide, hardened steel and ceramics. More recently lighter metals have been machined such as titanium alloys [1-15]. The aluminum alloy 7075 is one of the most important engineering alloys. It has been widely used as structural material in the transport applications, including marine, automotive and aviation applications due to their attractive properties, such as low density, high strength, ductility, toughness and resistance to fatigue [13]. During the precision machining of aluminum alloy by commercial methods, some problems take place on both machined surface and tool. The literature review showed that the selected materials in the studies are commonly tool steels, WC-Co, hardened steel and ceramics. The aluminum alloy 7075 is one of the most important engineering alloys. It has been widely used as structural material in the transport applications, including marine, automotive and aviation applications due to their attractive properties, such as low density, high strength, ductility, toughness and resistance to fatigue [13]. During the precision machining of aluminum alloy by commercial methods, some problems take place on both machined surface and tool.

In the last years, the Taguchi and analysis of variance (ANOVA) theory have been developed rapidly and caught the attention of many researchers. Hence, ANOVA based on Taguchi method was used for the efficiency of EDM process and the role on the relationship between the surface roughness and process parameters on AA7075 aluminum alloy.

II. EXPERIMENTAL PROCEDURE

The effects of EDM process parameters on the surface roughness of workpiece were statistically investigated with series of experiments performed in an ARISTEC LS350 EDM machine tool. 7075 aluminum alloy was used as the work piece material. The tempered at T651 work piece was machined in dimension of the 17x17x15 mm. Experiments were conducted under different process parameters, namely, current, pulse on-time, pulse off-time, gap voltage and electrode material. The machining depth was selected as 0.5mm and kept during all of the experiments. The dielectric fluid used in this study was Dielectrikum 358 oil. An electrode has a shape which is the inverse shape of the cavity. In order to see the effects of electrode material, two different electrodes, copper and graphite are used. The electrodes were machined in square size of 10x10 mm. The process parameters used in this study were presented at Table 1.

Table VI
EDM Process Parameters

Parameters	Levels		
	1	2	3
Electrode material	Copper	Graphite	-
Current [A]	4	7	10
Pulse on-time [µs]	4	6	8
Pulse off -time [µs]	2	3	4
Gap voltage [V]	50	60	70

A specially designed experimental procedure is required to evaluate the effects of machining parameters on the surface roughness. The use of traditional experimental design methods is generally complex and difficult. In addition, large number of experiments has to be carried out when number of machining parameters increases [16-18]. We used Taguchi method, a powerful tool for parameter design of performance characteristics, to determine optimal machining parameters in EDM. According to the Taguchi quality design concept, a L_{18} orthogonal arrays table with 18 rows (corresponding to the number of experiments) was chosen for the experiments (Table 2).

Table II
Experimental Design using L_{18} Orthogonal Array

Exp. No	A Electrode	B Current	C Pulse on-time	D Pulse off-time	E Gap voltage	R_a (µm)
1	1	1	1	1	1	3,69
2	1	1	2	2	2	4,55
3	1	1	3	3	3	4,03
4	1	2	1	1	2	7,17
5	1	2	2	2	3	8,33
6	1	2	3	3	1	9,10
7	1	3	1	2	1	10,54
8	1	3	2	3	2	12,22
9	1	3	3	1	3	13,24
10	2	1	1	3	3	3,37
11	2	1	2	1	1	4,70
12	2	1	3	2	2	4,77
13	2	2	1	2	3	9,46
14	2	2	2	3	1	8,07
15	2	2	3	1	2	9,50
16	2	3	1	3	2	11,07
17	2	3	2	1	3	12,63
18	2	3	3	2	1	12,10

The surface roughness (Ra) measurements were performed by using Mitutoyo Surftest (SJ 301). The Ra is used as the roughness parameters. Five measurements were taken at different region on the machined surface and the mean of these five measurements are taken as the final value for the surface roughness.

III.RESULTS AND DISCUSSION

In order to improve machining efficiency, reduce the machining cost, and improve the quality of machined parts, it is important to select the most appropriate process parameter conditions in a machining operation. The analysis of variance (ANOVA) was used to establish statistically significant machining parameters and the percent contribution of these parameters on the workpiece surface roughness. In Taguchi method [19], a loss function is used to calculate the deviation between the experimental value and the desired value. This loss function is further transformed into a signal-to-noise (S/N) ratio. There are several S/N ratios available depending on type of characteristics; lower is better (LB), nominal is best (NB), or higher is better (HB). The lower surface roughness is preferred in machining processes. Minimum surface roughness are an indication of better performance in EDM operations. For data preprocessing in the ANOVA process, surface roughness was taken as the “lower is better”. For LB, the definitions of the loss function (L) for cutting performance results y_i of n repeated number are:

$$S/N_{LB} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

Regardless of category of the performance characteristics, a greater S/N ratio value corresponds to better performance. Therefore, the optimal level of the EDM process parameters is the level with the greatest the S/N ratio value. The S/N ratio values for each experiment of L_{18} (Table 2) was calculated by applying the Equations 1 (Tables 3). Based on the analysis of S/N ratio, the optimal machining performance for the maximum surface roughness (Ra) was obtained at copper electrode material (level 1), 4A current (level 1), 4µs pulse on-time (level 1), 4µs pulse off-time (level 3) and 50V gap voltage (level 1) settings. The optimal machining parameter levels can be shortly given as A1, B1, C1, D3 and E1. Fig 1 indicates the effect of machining parameters on the Ra and the response graph of each level of the machining parameters.

Table III
S/N Ratio Values for Ra

Machining factor	Mean S/N ratio by factor level (dB)		
	1	2	3
A	-17.32*	-17.70	-
B	-12.36*	-18.65	-21.53
C	-16.64*	-17.82	-18.08
D	-17.65	-17.79	-17.10*
E	-17.36*	-17.66	-17.50
Overall mean = -17.51 dB *Optimum level			

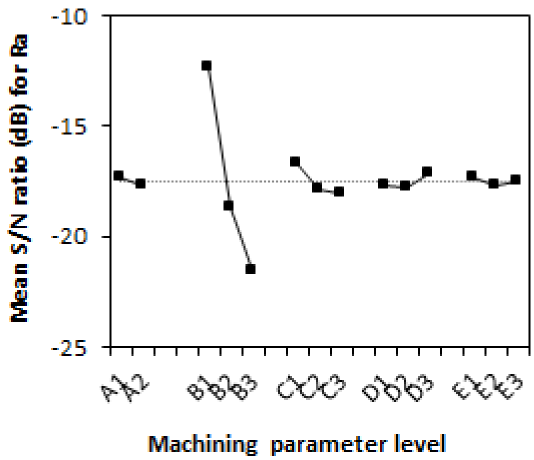

Fig. 3 The effect of machining parameters on surface roughness

A better feel for the relative effect of the different machining parameters on the surface roughness was obtained by decomposition of variance [20]. The relative importance of the machining parameters with respect to the surface roughness was investigated to determine more accurately the optimum combinations of the machining parameters by using ANOVA. The results of ANOVA for the machining outputs are presented in Table 4. Statistically, F-test provides a decision at some confidence level as to whether these estimates are significantly different [19,20]. Larger F value indicates that the variation of the process parameter makes a big change on the performance characteristics. F values of the machining parameters are compared with the appropriate confidence table. When the F value of the machining parameter are bigger than $F_{\alpha,v1,v2}$ value of the confidence table, where α is risk, v_1 and v_2 are degrees of freedom associated with numerator and denominator.

Table IV
Result of ANOVA for Ra

Process parameter	Degree of freedom (df)	Sum of square (SS_A)	Variance (V_A)	F	Contribution % (ρ_p)
A	1	0.64	0.64	0.96	0.23
B	2	263.98	131.99	199.19	94.66
C	2	7.06	3.53	5.32	2.53
D	2	1.63	0.81	1.22	0.58
E	2	0.27	0.13	0.20	0.10
Error	8	5.30	0.66	-	1.90
Total	17	278.87	-	-	100

According to the analysis in this study, the most effective parameters with respect to the surface roughness are current whereas the effect of electrode material, pulse on-time, pulse off-time and gap voltage on the surface roughness was insignificant. Percent contribution indicates the relative power of a factor to reduce variation. For a factor with a high percent contribution, a small variation will have a great influence on the performance. The percent contributions of the machining parameters on the surface roughness are shown in Table 4. According to Table 4, current was found to be the major factor affecting the Ra (94.66%), whereas pulse on time was found to be the second ranking factor (2.53%). However, the percent contribution of pulse off-time, tool electrode material and gap voltage is much lower, being 0.58%, 0.23% and 0.10%, respectively. The order of importance of the controllable factors on the surface roughness in the machining operation can be listed as: factor B (current), C (pulse-on time), D (pulse-off time), A (electrode material) and E (gap voltage),. This indicates that the surface roughness was strongly affected by the discharge current.

IV. CONCLUSIONS

In this study, effect of machining parameters on workpiece surface roughness in EDM was investigated by using ANOVA based on Taguchi method. The minimum surface roughness was selected to be the quality target. Based on ANOVA method, the highly effective parameters on the surface roughness were found as discharge current, whereas pulse on-time, pulse off-time, electrode material and gap voltage were less effective factors. The discharge current was the strongest factor among the other machining parameters used on the surface roughness. The importance of the controllable factors on the performance characteristics was in order of discharge current>pulse on-time>pulse off-time>electrode material>gap voltage. An optimum parameter combination for the maximum surface roughness was obtained by using the analysis of S/N ratio. The optimal machining parameter levels can be shortly given as A1, B1, C1, D3 and E1.

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